The research program of the Center for Economic Studies produces a wide range of theoretical and empirical economic analyses that serve to improve the statistical programs of the U. S. Bureau of the Census. Many of these analyses take the form of research papers. The purpose of the Discussion Papers is to circulate intermediate and final results of this research among interested readers within and outside the Census Bureau. The opinions and conclusions expressed in the papers are those of the authors and do not necessarily represent those of the U. S. Bureau of the Census. All papers are screened to ensure that they do not discluse confidential information. Persons who wish to obtain a copy of the paper, submit comments about the paper, or obtain general information about the series should contact Sang V. Nguyen, Editor, Discussion Papers, Center for Economic Studies, Room 1587, FB 3, U. S. Bureau of the Census, Washington, DC 20233-6300, (301) 763-2065.

# SCIENCE, R&D, AND INVENTION POTENTIAL RECHARGE: U. S. EVIDENCE*

By

James D. Adams**

Ces 93-2 January 1993

## Abstract

The influence of academic science on industrial R&D seems to have increased in recent years compared with the pre-World War II period. This paper outlines an approach to tracing this influence using a panel of 14 R&D performing industries from 1961-1986. The results indicate an elasticity between real R&D and indicators of stocks of academic science of about 0.6. This elasticity is significant controlling for industry effects. However, the elasticity declines from its level during the 1961-1973 subperiod, when it was 2.2, to 0.5 during the 1974-1986 subperiod. Reasons for the decline include exogenous and endogenous exhaustion of invention potential, and declining incentives to do R&D stemming from a weakening of intellectual property rights. The growth of R&D since the mid-1980s suggests a restoration of R&D incentives in still more recent times.

Keywords: R&D, science, technical change.

* I thank Adam Jaffe for his comments. The findings and conclusions of this paper are those of the author and do not necessarily reflect the views of the U.S. Bureau of the Census.

** Department of Economics, University of Florida, and Center for Economic Studies, Bureau of the Census.

The role played by academic science in industrial R&D seems to have increased. Anecdotal evidence for this view can be found in Rosenberg (1982), Hounshell and Smith (1988), and Mowery and Rosenberg (1989). Statistical support is provided by the rapid growth of scientific employment in industry (National Science Foundation [1990]), signalling a greater willingness to pay for advanced training. The source of the change is very likely an increasing division of labor in the knowledge producing industries (Becker and Murphy [1992]), in which university research enhances the returns to industry R&D. The postwar surge in government finance of academia has in the meanwhile boosted the flow of new results. In this paper I marshal some evidence to test the assertion that science replenishes the returns to R&D. This turns out to be mildly supportive.

## I. Framework

A microeconomic justification for the science-R&D recharge mechanism is provided by the search theoretic approach to R&D (Evenson and Kislev [1976]). The following development of this approach is drawn from Adams and Sveikauskas [1992]). Consider a Cobb-Douglas production function for an R&D firm, $q_t=A_t J_i z_{it}$, where $q_t$ is output, $A_t$ is current productivity, and the $z_{it}$ are inputs. Improvements in $A_t$ depend on innovations that are discovered randomly, so future increases in $A_t$ are random. These depend on

R&D activity, which is a function of research scientists and engineers $R_t$ and other R&D inputs. For reasons of data availability I ignore other R&D inputs and focus on $R_t$ in the innovation process. In this case R&D expenditures are simply $w_t R_t$, and they are driven by determinants of $R_t$ which include science, R&D spillovers, and perhaps the firm's own past R&D, though the empirical focus here will be on academic science. To see the effect of science on recharge, let the mean of a, the random variable for which $A_t$ is the current realization, shift to the right with the stock of academic science $S_t$. The probability of no improvement is $Pr(a<A_t)=F_t(C)$. This increases with the upper limit $A_t$ but it declines as R&D scientists and the stock of knowledge $R_t$ and $S_t$ increase. Also let $R_t$ and $S_t$ be complementary in reducing the probability of no improvement. Therefore, $Pr(a<A_t)=F(A_t,R_t,S_t)$, with the properties $F_1>0$, $F_2<0$, $F_3<0$, $F_{23}<0$.

The firm seeks to maximize expected present value $EV_t$, the sum of current profits and discounted present value next period. The latter is in turn the value if productivity remains the same times the probability of it remaining the same, plus the expected value given various degrees of productivity improvement. Where $B_t$ is the flow of current profits, and $f(a_{t+1},C)$ is the density function for $a_{t+1}$ we have

$$EV_t(\boldsymbol{A}_t,S_t)=\max_{Z_{it},\,\ell_t}\{\pi_t+\beta[F_t(\boldsymbol{A}_{t+1},\bullet)EV_{t+1}(\boldsymbol{A}_t,S_{t+1})+\int_{\boldsymbol{A}_t}^{\infty}f_t(\boldsymbol{a}_{t+1},\bullet)EV_{t+1}(\boldsymbol{a}_{t+1},S_{t+1})\,d\boldsymbol{a}_{t+1}]\}. \qquad \textbf{(1)}$$

This problem yields separable first order conditions for the $z_{it}$ on the one hand and for $R_t$ on the other, with the former depending on current conditions and the latter depending on expected future market conditions and knowledge $S_t$. The condition for scientists and engineers is

$$\frac{\partial F_t(\bullet)}{\partial \ell_t} EV_{t+1}(\mathbf{A}_{t+1}) + \int_{\mathbf{A}_t}^{\infty} \frac{\partial f_t(\bullet)}{\partial \ell_t} EV_t(\mathbf{a}_{t+1})\, \mathbf{da}_{t+1} = w_t, \tag{2}$$

where $w_t$ is the wage of $R_t$. The hypothesis that science raises the odds of higher valued states at the expense of lower valued is $M^2EV_t/MR_tMS_t>0$. The value function is concave in scientists and engineers, so $M^2EV_t/M^2R_t<0$. Therefore $MR_t/MS_t= -M^2EV_t/MR_tMS_t/M^2EV_t/M^2R_t>0$. Given that R&D spending is $w_tR_t$ in our simple case, $MRD_t/MS_t=w_tMR_t/MS_t>0$. The industry response is derived by aggregating the individual responses, which may differ by firm and industry due to heterogeneity in linkages to science.

In principle more detail could be added by breaking up science into new and old branches, thereby allowing the range of science to promote R&D, as in the models of growth due to specialization of Romer (1987, 1990). If it could be measured with an index number like that of Feenstra, Markusen, and Zeile (1992), this might be another source of recharge.

## II. Data

The focus of this paper is on the relationship between science and R&D. For the dependent variable I use National Science Foundation data on total and company-financed R&D expenditures by industry of reporting firms rather than by applied product field[1]. Expenditures are in millions of 1972 dollars. The data form a panel of 14 R&D performing industries over the period 1961-1986.

I supplement the R&D data with evidence on world-wide flows of scientific publications in nine broadly defined sciences. Modified in a way described just below, these serve as science indicators to test the science-R&D relationship[2]. The flows are long time series usually beginning before 1930. I accumulate the flow for the jth science into a stock $N_j$ in units of 100,000 papers, assuming a rate of obsolescence of 11 percent per year. Note that the results are insensitive to the choice of obsolescence rates in the range of 9-13 percent. I then aggregate the $N_j$ into an aggregate knowledge index $KN_i$ for the ith industry by weighting the article count stocks by respective scientists and engineers in each industry, so that $KN_i=\Sigma_j w_{ij} N_j$. I choose $w_{ij}$ to be the share of field j scientists in scientific employment in industry i lagged 5 years, so that $\Sigma_j w_{ij}=1$. The resulting stocks grow roughly at the rate of 1 percent a year. Some scheme is necessary in order to capture industry differences in the mix of sciences, even though every such scheme reflects a degree of endogeneity[3]. In this sense shares seem preferable to numbers of scientists as weights since they are more exogenous.

This being said, the specification of the industry knowledge index $KN_i$ in terms of $w_{ij}$ shares is very limiting. Cross-industry differences in the acquired volume of science are greatly diminished by this choice. The focus on time series aspects in the index generates collinearity among different effects that one would like to distinguish, especially effects of recent flows versus inherited stocks of knowledge.

## III. Empirical Findings

Table 1 contains representative estimates of the science-R&D relationship for the entire period. Since both R&D and stocks of knowledge are expressed in logarithms, the knowledge coefficient is the elasticity of R&D with respect to science. The dependent variable is the log of real R&D expenditures. All equations in Table 1 include the Federal Reserve's index of capacity utilization and a time period dummy for the post-1973 era.

Both of equations (i) and (ii) use the log of total R&D as the dependent variable but (i) omits industry dummies while (ii) includes them. Recall that cross-industry differences in the utilization of science are greatly attenuated in the knowledge index, in fact much below their true level. For this reason, and since the industry dummies which control for R&D propensities are omitted, the science-R&D elasticity in (i), and its level of significance may be regarded as rough lower bounds on the true values. This interpretation is borne out in (ii), which does include industry effects. Though the elasticity is not very different, 0.6 rather than 0.5, the coefficient switches from insignificant to highly significant.

Equations (iii) and (iv) report similar results for company financed R&D. Since private R&D is more dependent on the incentives to do R&D, it is not surprising that the fit improves compared with (i) and (ii). Both the level of significance and the elasticity rise in (iii) as compared with (ii), but the elasticity, which is about 0.6, is again significant only if industry effects are netted out. In each case this is because industry effects are negatively correlated with the index, from which cross-sectional effects are largely omitted. Considered as a group the findings are mildly favorable to the notion of a link between science and R&D, but with some caveats. For one thing, it is quite difficult to separate time trend from the influence of knowledge accumulation in these aggregative data. For another, my attempts to explain percentage growth in real R&D met with mixed results. The science-R&D elasticities were insignificant in regressions of growth in R&D on growth in the surrogate knowledge stocks. Next, as suggested in Griliches (1979) to allow for cross-industry differences in the science-R&D elasticity, I transformed the product of the elasticity and knowledge growth into the product of the return on knowledge and the ratio of the change in knowledge to real R&D, with R&D lagged in the ratio by

5 years to take account of the correlated structure of errors in the R&D data[4]. In the intensity form the estimated effects are often positive and significant, but overall the results for growth in R&D spending are still mixed. Perhaps these results are not surprising given the noise involved in first differencing, and given the fact that percentage changes in R&D probably capture year-to-year changes in the luck associated with R&D.

In order to test the stability of the science-R&D elasticity over time, and especially its possible decline in recent years, Table 2 breaks the sample into sub-periods centered on the year 1973. What I find is that the elasticity is significantly larger during the earlier period[5]. This suggests that the connection between science and R&D did weaken during the late 1970s . The sources of the decline are not obvious, and they fall outside the scope of this paper. Different explanations include diminishing recharge of R&D by science (Evenson [1993]), an increase in the value of invention, leading firms to exploit lesser inventive opportunities (Kortum [1993]), and perhaps declining intellectual property rights and incentives to exploit research opportunities. The recovery of R&D in recent years from its low in the late 1970s as a percent of GDP suggests a recovery of research opportunities and argues against the permanence of declining opportunities.

The tests conducted in this paper are incomplete in that they neglect linkages between patenting and science. I am also inclined to think that the connection between academic science, industrial R&D, and patenting could be further illuminated by the use of microdata on individual firms. This would resolve problems of time series collinearity through the intrinsically larger and more independent variability in such data, and it would help answer questions about the endogeneity of industrial scientific resources in the face of seemingly epochal changes in our knowledge of the world.

**Table 1- Science and R&D: Full period Regressions**

Dependent Variable is log(real R&D)

(t-statistics in parentheses)

| Variable | Equation (i) | (ii) | (iii) | (iv) |
|---|---|---|---|---|
| Definition of R&D | Total | Total | Company Financed | Company Financed |
| Industry Dummies | No | Yes | No | Yes |
| Log (weighted knowledge stock per scientist and engineer)[a] | 0.470<br>(1.0) | 0.588<br>(7.9) | 0.634<br>(1.6) | 0.583<br>(7.2) |
| Adjusted $R^2$ | 0.010 | 0.978 | 0.025 | 0.964 |
| N | 364 | 364 | 364 | 364 |

Note. Time period is 1961-1986. All equations include a time period dummy for the post-1973 period of the productivity slowdown, and the FRB index of capacity utilization. [a] Definition is $3_j\ s_{ij}N_j$, where $s_{ij}$= share of field j scientists in industry i employment of all scientists and engineers. Both numbers and shares of scientists are lagged 5 years.

**Table 2- Science and R&D: Sub period Regressions**

Dependent Variable is log(real company financed R&D)

(t-statistics in parentheses)

| Variable | (i) | (ii) |
|---|---|---|
| Industry Dummies | Yes | Yes |
| Log (weighted knowledge stock per scientist and engineer)[a] | 2.233<br>(5.6) | 0.560<br>(14.1) |
| Adjusted $R^2$ | 0.980 | 0.992 |
| N | 182 | 182 |
| Time Period | 1961-1973 | 1974-1986 |

Note. Equations include the FRB capacity utilization index.[a] See the notes to Table 2 for the definition of this variable.

## FOOTNOTES

[1] See National Science Foundation, Research and Development in Industry (various years). One reason for the choice of data is that R&D by applied product field data exhibits declining quality, owing to a drop in the response rate, after 1981.

[2] The nine sciences are agriculture, biology, chemistry, computer science, engineering, geology, mathematics and statistics, medicine, and physics. For sources, see Adams (1990).

[3] An alternative is to use subjective weights from surveys of business executives concerning the relative importance of the various sciences in different lines of business.

[4] See Griliches and Hausman (1986) for a discussion of the problem of identifying the structure of errors in panel data. In the present case, prior smoothing of the R&D expenditures data were known to have created autocorrelation. This made a 5 year lag L in )$KN_t/R\&D_{t-L}$ imperative in the intensity regressions.

[5] The F statistic is $F(1,332)=27.2$, where $F_{0.99}(1,332).6.73$. Its numerator is the residual sum of squares when the science-R&D elasticity is forced to be the same over the entire period, minus the residual sum of squares when it is allowed to differ between the two sub- periods. Its denominator is the residual sum of squares divided by 332 degrees of freedom, or the mean square.

## REFERENCES

**Adams, James D.,** "Fundamental Stocks of Knowledge and Productivity Growth," Journal of Political Economy 98 (August 1990): 673-702.

________________**, and Sveikauskas, Leo,** "Academic Science, Industrial R&D, and the Growth of Inputs," Center for Economic Studies, U.S. Bureau of the Census, November 1992.

**Becker, Gary S., and Murphy, Kevin M.,** "The Division of Labor, Coordination Costs, and Knowledge," Quarterly Journal of Economics 107 (November 1992): 1137-1160.

**Evenson, Robert E., and Kislev, Yoav,** "A Stochastic Model of Applied Research," Journal of Political Economy 84 (April 1976): 265-281.

__________________, "Patents, R&D, and Invention Potential: International Evidence," forthcoming in American Economic Review 83 (May 1993).

**Feenstra, Robert C., Markusen, James R., and Zeile, William,** "Accounting for Growth With New Inputs: Theory and Evidence," American Economic Review 82 (May 1992): 415-421.

**Griliches, Zvi,** "Issues in Assessing the Contribution of Research and Development to Productivity Growth," Bell Journal of Economics 10 (Winter 1979): 92-116.

_______________**, and Hausman, Jerry A.,** "Errors in Variables in Panel Data," Journal of Econometrics 31 (January 1986):93-118.

**Hounshell, David A., and Smith, John Kenley,** Science and Corporate Strategy: DuPont R&D, 1902-1980, Cambridge, U.K., Cambridge University Press, 1988.

**Kortum, Sam,** "Equilibrium R&D and the Patent-R&D Ratio: U.S. Evidence," forthcoming in American Economic Review 83 (May 1993).

**Mowery, David C., and Rosenberg, Nathan,** Technology and the Pursuit of Economic Growth, Cambridge, U.K., Cambridge University Press, 1989.

**Romer, Paul M.,** "Growth Based on Increasing Returns Due to Specialization," American Economic Review 77 (May 1977): 56-62.

________________, "Endogenous Technical Change," Journal of Political Economy 98 (Supplement, October 1990): S71-S102.

**Rosenberg, Nathan,** Inside the Black Box: Technology and Economics, Cambridge, U.K., Cambridge University Press, 1982.

**National Science Foundation,** Science and Engineering Personnel: A National Overview, Washington, U.S. Government Printing Office, 1990.

______________________________, Research and Development in Industry, Washington, U.S. Government Printing Office, various years.